

## **CHARACTERIZATION OF CYLINDRICAL STRUCTURE FABRICATED USING GLASS FIBER REINFORCED POLYMER AND MACHINED BY ABRASIVE JET MACHINING**

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### **ABSTRACT**

Composite materials play an important role in many industrial applications. Researchers around the world are working to create new composites to improve the usefulness of these materials. GRP (Fiberglass Reinforced Polymer) is a composite material made from a fiberglass reinforced polymer matrix. They have better stiffness, strength, electrical conductivity, low coefficient of thermal expansion, excellent fatigue resistance, and the ability to produce materials of complex shapes. In this study, different layers of different types of fiberglass cloth are used to manually manufacture fiberglass reinforced polymer hollow cylinder components and test the torsional and compressive strength of the sample. There are various fiberglass fabrics such as veil mats and textiles. Analysis is performed on the different types of samples generated to see if they are suitable for different applications. The results of the study show the effect of different layers of fiberglass on their strength and the possibility of replacing the weakly transmitting metal shaft with a composite shaft (GRP).

**Keywords :** Composite; Machining; Abrasive jet

### **I. INTRODUCTION**

A composite material is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components [1-7]. The individual components remain separate and distinct within the finished structure. The new material may be preferred for many reasons: common examples include materials that are stronger, lighter, or less expensive when compared to traditional materials. Since a composite material that could be less cost and reduced weight is capable of replacing the conventional materials, it has to be tested in terms of various strengths based on their replacing application and material. Likewise, lots of research works are being conducted in the composite world [8-12]. Machining of composite by conventional methods may lead to delamination of the composites which in turn will not provide the necessary dimensional aspect. Hence researchers have adopted

unconventional methods of machining the composites [13-18]. Abrasive jet machining is one of the common unconventional method used for machining the composites [19-24].

Fiber-reinforced polymer is a composite material which are made of a polymer matrix reinforced with fibers are usually glass, carbon, aramid, or basalt. Rarely, other fibers such as paper or wood, or asbestos have been used. The polymer is usually an epoxy, vinylester, or polyester thermosetting plastic, and phenol-formaldehyde resins are still in use. These materials specifically use fiber materials to augment the strength and elasticity of plastics. The conventional plastic material without fiber is called as the matrix. The matrix is tough but relatively weak and hence strengthened by the addition of stiffer reinforcing filaments or fibers. The extent to which the strength and elasticity is incorporated depends on the mechanical properties of both the fiber and matrix. The objective of fiber-reinforced composites is to obtain a material with high

specific strength and high specific modulus. (i.e. high strength and high elastic modulus for its weight.) The strength is obtained by having the applied load transmitted from the matrix to the fibers. Hence, interfacial bonding is important.

**GLASS FIBER REINFORCED POLYMER (GRP)** is a material derived from fine fibers of glass. Fiber glass is a lightweight, extremely strong, and robust material. This is less brittle than carbon fibre and less expensive. When compared to metals, bulk strength and weight properties are favorable and can be easily formed by the moulding processes. Glass is the oldest, and most familiar, performance fiber.

There are several types of glass fibers in use. They are A-glass (Alkali-lime glass with little or no boron

oxide), ECRglass (Electrical/Chemical Resistance; alumino-lime silicate with less than 1% w/w alkali oxides, with high acid resistance), C-glass (alkali-lime glass with high boron oxide content, used for glass staple fibers and insulation), D-glass (borosilicate glass, named for its low Dielectric constant), R-glass (aluminosilicate glass without MgO and CaO with high mechanical requirements as reinforcement), and S-glass (aluminosilicate glass without CaO but with high MgO content with high tensile strength).

## II. RESEARCH GAP:

As we have seen that in so many studies, research works, and projects have been carried out regarding the glass fiber reinforced polymer to test its strength in various aspects. Various literature demonstrated the composite as strips to examine various mechanical properties. Also, this set of tests has been conducted by changing the orientation of the fiber in the specimen (strip) to determine its strength degradation based on the varying orientation of the fiber. In another set of research, the polymer is added to concrete and designed in to a cylindrical structure and tested for compressive and torsional behavior. The above study has been experimented in real-life applications as a support column for extensive structures.

In this study, the composite is fabricated as a hollow member with 4 different layers in the specimen. These specimens are subjected to torsion

and compression loading to find the strength degradation among these four variations which are nothing but the different types of fiber orientations in the layers of the specimen.

## III. DIFFERENT TYPES OF ORIENTATION

Along the axis, the material under study is both rigid and robust in tension and compression. Fibers may be considered weakly compressed, but only if the fiber has a long aspect ratio. In other words, common fibers are long and thin, which makes them easy to twist. On the other hand, glass fiber has a weak shear force, that is, it crosses its axis. Therefore, if the aggregate of fibers can be permanently placed in the preferred direction within the material and can prevent strain under pressure, the material will be preferentially stronger in that direction. In addition to building multiple layers in different priority directions, you can efficiently control the overall stiffness and strength of the material. For fiberglass, it is the plastic matrix that permanently presses the structural fiberglass in the direction chosen by the designer. For staple bats, this direction is basically the entire 2D plane. Woven fabrics or unidirectional layers provide more precise control over the direction of in-plane stiffness and strength.

In this study, the following types of fiberglass mats (fabrics) are used to analyze changes in the mechanical properties of FRP samples for different orientation types across different layers of the sample. The following describes different orientation types with fiber layups placed in different layers for comparative analysis.

- In Type-one all four layers of the hollow cylindrical specimen are wrapped with pure unidirectional (Zero degree – orientation) fiber fabrics. [Uni – 4 layers]
- In Type-two the inner and the outer layers were are enveloped with the unidirectional fiber fabrics (Zero degree - orientation) and the central two layers were covered with Chopped Strand Mat (CSM). [0°/CSM/CSM/0°]
- As far as Type-three is concerned, layers of the specimen were covered with the Bi-directional (0°-90° orientation) glass fiber fabrics. [Bi – 4 layers]
- The inner and outer layers of Type-four were covered with unidirectional fiber

fabrics (Zero degree - orientation). The next layer from the outer layer is covered with 135° oriented (-45°) fiber fabrics and the second layer from the innermost layer is wrapped with 45° oriented fiber fabrics. It should be noted that both -45° and 45° orientation fiber fabrics are cut from the unidirectional fiber mat for the required dimension using an angled template. [ 0°/-45°/45°/0°]

#### **IV. NOMENCLATURE**

Generally, the nomenclature is defined as the devising or choosing of names for things, especially in science or other disciplines.

- Specimen with unidirectional fiber orientation is denoted as UNI.
- Specimen with chopped strand mat is denoted as CSM.
- Specimen with 45-degree fiber orientation is denoted as 45.

Specimen with bidirectional fiber orientation is denoted as BI.

#### **V. REINFORCEMENT PROCESS**

The fabrication steps of our GFRP hollow cylindrical specimens are explained as follow:

##### **A) PREPARATION OF MANDREL:**

The mandrel that has been used is nothing but the PVC pipe which is cheaply available in the market. The PVC pipe with an outer diameter of 25mm and length of 350mm or more is taken first. Then it is made into two pieces by cutting it in the middle. Then the two cut pieces are joined into a single piece with the help of cellophane tape. The Polythene sheet with 297mm length is wrapped around the pipe closely without any air gaps with the help of the tape.

##### **B) PREPARATION OF GLASS PLATE:**

The glass of 1000mm length and 1000mm width is taken. To keep the surface free from any impurities, acetone is used.

##### **C) WAX COATING**

This manual reinforcement process uses wax polish as a mold release agent. A thin coat of wax polish is applied to the polyethylene sheet wrapped around the tube to facilitate sample removal after curing. The glass plate is also coated with a thin layer of wax to prevent FRP from adhering during the reinforcement process

#### **D) RESIN AND HARDENER PREPARATION**

A small ceramic bowl is taken. Clean with an acetone solution to remove any impurities. A resin (Araldite 1y556) equal to the weight of the fiber is placed on the tray. The hardener, which is 10% by weight of the resin, is mixed with the resin in a ceramic bowl. The resin and hardener need to be finely mixed in the bowl.

#### **VI. COMPONENTS REQUIRED**

Several types of equipment and components were utilized during the fabrication and the analysis phase of this study project. A detailed description of those materials, tools, and types of equipment are given as follows:

- Glass fiber mat
- Resin – epoxy (Araldite - 1y556)
- Hardener (aradur - hy951)
- Consolidation roller
- Fiber cutter
- Fiber cutter
- Universal testing machine
- Torsion testing machine
- Tensile testing machine

#### **VII. TORSION TESTING**

Torsion tests twist a material or test component to a specified degree, with a specified force, or until the material fails in torsion. The specimen is twisted by applying torque on one end and holding the other end. If you wish to apply torque on both the sides, it should be applied in opposite direction. The science studied through this experimentation is similar to the test performed with a string that was hold on one side and the other end twisted.

##### **A) SPECIMEN PREPARATION :**

Since the specimen holder in the conventional torsion testing machine can hold only a rod of

maximum diameter of 12mm or a rectangular strip of width 12mm, we require an additional arrangement for holding as the mean diameter of the specimen we fabricated is itself around 29.67 mm. Hence, it was decided to hold the sample utilizing a T-joint. In order to do so, the sample was machined using an 8 mm drill; 6 mm from both ends.

#### **B) SPECIMEN HOLDING TECHNIQUE (T-JOINT) :**

This T-joint comprises two parts. One is a flat metal strip of 3mm thickness, length 12mm, and width 2mm with an 8mm hole drilled at each of its ends. The strip is aligned parallel to the axis of the test piece, one end of the strip is inserted into the machine's workpiece holder and the other end penetrates the hollow cylindrical test piece and becomes the axis of the metal drill hole. It is oriented like this. The strip must be coaxial with the bore of the test piece. The second part of the joint is a metal rod with a diameter of 8 mm that must be inserted laterally into all aligned holes in both the sample and the metal strip.

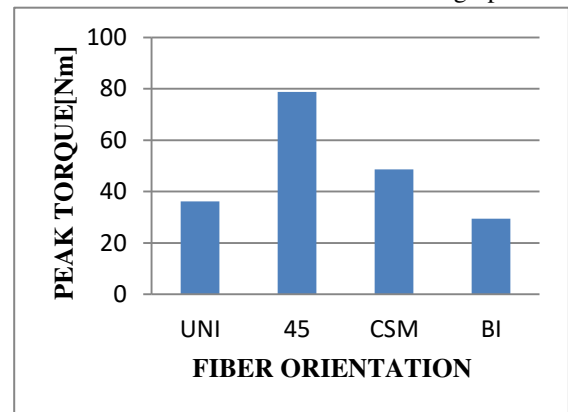
. In this same way, the specimen is connected to the work holder of the machine with the help of a T-joint on both sides. It is ascertained that all the holes machined have been provided with necessary tolerances for flawless alignment and fastening before applying the torque.

#### **C) TEST PROCEDURE :**

- The sample is flawlessly detained in the machine through the joints. In order to record the data, a data acquisition system accompanied by a torsion tester is setup in the machine.
- Since the specimen has one end fixed, the lever connected to the motor is used to manually rotate the other end without turning on the motor electrically (rotational motion).
- Every 10 revolutions, the corresponding torque and angle of rotation values are recorded from the digital data acquisition system. Keep in mind that the number of revolutions must be constant. This continues until the sample is

untwisted. The breakpoint value is then retrieved from the data acquisition system.

- Next, plot a graph between the torque value and the corresponding helix angle to show the change in twist due to the helix angle and maximum torque value. Torsional force can also be applied by switching on the electric motor. However, if you do this, you will only get breakpoints and you will not be able to plot the graph.



**Fig.1 Peak Torque Analysis**

From Figure 1, we can conclude that the 45 degree fiberglass oriented sample has the highest torque transfer capability and the bidirectional glass fiber oriented sample has the lowest torque transfer capability. The CSM fiber oriented sample has a smaller torque capacity than the 45 degree fiber oriented sample, but has a larger torque capacity than the unidirectional fiber oriented sample.

#### **VIII. TEARING TEST**

This tear test is a rare type of test performed to measure the edge tear strength of a fiberglass cylindrical specimen. Perform this tear test using a conventional tensile tester. The basic intention of this test is to determine the maximum load this fiber specimen withstands before it tears off at the edges after applying axial load by penetrating the support hook at the top and bottom of the specimen and pulling apart.

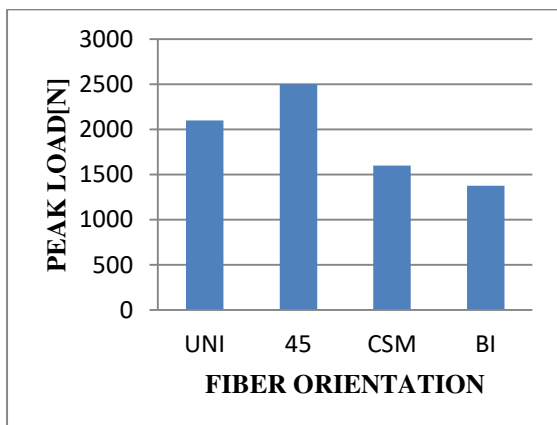
#### **A) SPECIMEN PREPARATION :**

The length of the sample prepared for analysis is 22 mm. To hang the test piece on the hook of the

tensile tester, drill the test piece with an 8 mm drill at a distance of 6 mm from both ends of the cylindrical test piece, similar to the torsion test.

#### **B) TEST PROCEDURE :**

- The test piece is secured to the machine by hooks on both ends and tightened to the optimum level for applying an axial load. The dial gauge load value is set to zero.
- Load in the axial direction is enabled with the help of the lever provided at the bottom the machine.
- Load pertaining to 0.1 mm increment of deflection is also monitored.
- Deflection in the axial direction and the load pertaining to it is monitored until the sample tears off.



**Fig.2 Peak Load for Tearing**

From Fig.2, it could be concluded that the specimen with a 45-degree glass fiber orientation has the maximum capacity to resist tearing. It can be able to withstand a load greater than 2500 N. Since the machine we used can apply only load up to 2500 N, we cannot find the accurate value. The sample possessing unidirectional orientation tends to take more tear load than the sample with other orientation. In contrary, bidirectionally oriented specimen possess less capacity to hold tear load.

#### **IX. COMPRESSION TESTING**

Compression testing is a very common testing method that is used to establish the compressive force or crush resistance of a material and the ability of the material to recover after a specified

compressive force is applied and even held over a defined period. The maximum stress a material can sustain over a period under a load (constant or progressive) is determined. The specimen is compressed and deformation at various loads is recorded. Compressive stress and strain are calculated and plotted as a stress-strain diagram which is used to determine elastic limit, proportional limit, yield point, yield strength, and, for some materials, compressive strength.

#### **A) SPECIMEN PREPARATION :**

As mentioned earlier one of the mottoes of the compression testing in this study is to compare the strengths of the cylindrical specimen among different aspect ratios. For this reason, the original dimension (Length = 22mm, Mean Diameter 29.67mm) which could be taken as 100% is divided as 75%, 50%, 25%, and thus 4 such specimens are prepared for each of the orientation types. Thus four fibre orientation, totally 16 samples are tested for compression. All the samples under testing are sheared to 22 mm length according to the desired aspect ratio and their surface were machined to have a smooth surface.

#### **B) TEST PROCEDURE :**

- The specimen is placed vertically at the perfect center in the lower half portion of the UTM where the compression is done with help of the upper plane tool which pushes the specimen towards the base in the axially downward direction.
- The Data Acquisition system and a computer system installed with the WinUTM software to retrieve the digital reading and the graph representing the strength respectively are connected to the UTM.
- Both the machine and the Digital systems are activated at the same time and thus load is applied by the UTM and the values and graphs are generated by the computer system simultaneously.
- After each specimen is broken the same test procedure is repeated for all 16 specimens.

At the end of the compression test it is ascertained that deformation takes place at the edge in a flower pattern and buckling does not happen.

#### Comparison among unidirectional orientation with the various aspect ratio

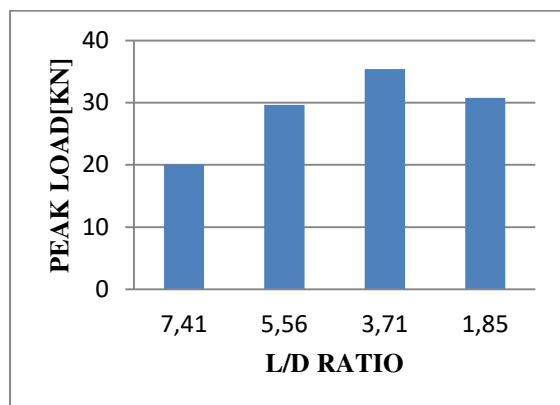


Fig.3 Peak Load in Compression

Among the **unidirectional orientation glass fiber** (TYPE-1) the specimen with an aspect ratio of 3.71 is having the ability to withstand the highest peak load (compressive) and the specimen with an aspect ratio of 7.41 is having the ability to withstand the lowest peak load. The specimen with an aspect ratio of 1.85 withstands a lesser peak load than that of 3.71 (Fig.3) but the same specimen withstands a greater peak load than the specimen of aspect ratio 5.56.

#### Comparison among various fiberorientations with aspect ratio-1.85 (Fig.4)

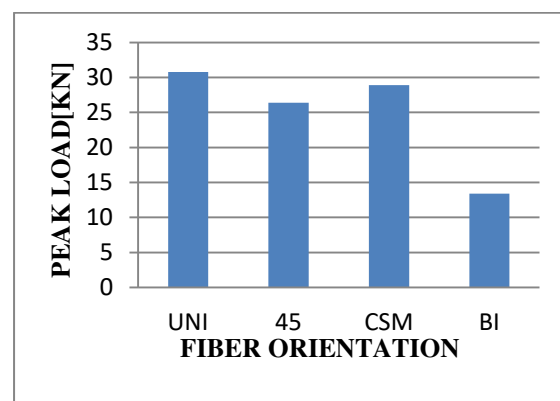


Fig.4 Peak Load and Fibre Orientation

Among the **unidirectional orientation glass fiber** (TYPE-1) the specimen with an aspect ratio of 5.56

is having the highest crosshead travel (compressive) for breaking and the specimen with an aspect ratio of 7.41 is having the lowest crosshead travel (CHT). The specimen with an aspect ratio of 1.85 has lesser crosshead travel (CHT) than that of 5.56 but the same specimen has greater crosshead travel (CHT) than the specimen of aspect ratio 3.71.

#### D) CROSSHEAD TRAVEL ANALYSIS FOR COMPRESSION :

##### Comparison among unidirectional orientation with the various aspect ratio (Fig.5)

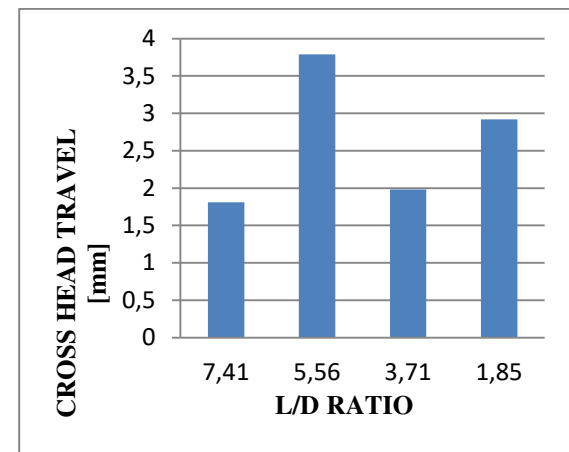
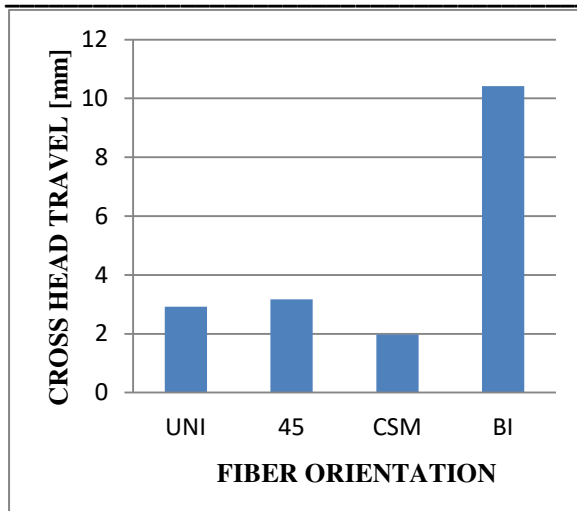


Fig.5 Cross Head Travel Vs L/D ratio

Among the **unidirectional orientation glass fiber** (TYPE-1) the specimen with an aspect ratio of 5.56 is having the highest crosshead travel (compressive) for breaking and the specimen with an aspect ratio of 7.41 is having the lowest crosshead travel (CHT). The specimen with an aspect ratio of 1.85 has lesser crosshead travel (CHT) than that of 5.56 but the same specimen has greater crosshead travel (CHT) than the specimen of aspect ratio 3.71.

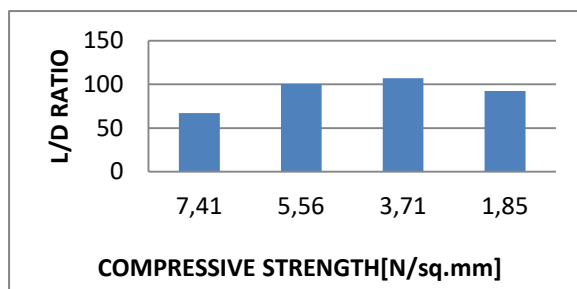
##### Comparison among various fiberorientations with aspect ratio-1.85 (Fig.6)



**Fig.6 Cross Head Travel Vs Fibre Orientation**

The specimen with aspect ratio of 1.85 (TYPE-1) delivers uppermost head travel and the sample having bidirectional orientation (TYPE-3) delivers the least head travel. Chopped mat sample (TYPE-2) delivers least CHT when compared to unidirectional (TYPE-1) sample, however, the same sample delivers higher CHT than the 45-degree cross-ply orientation (TYPE-4) specimen.

**Comparison among unidirectional orientation with a various aspect ratio (Fig.7)**

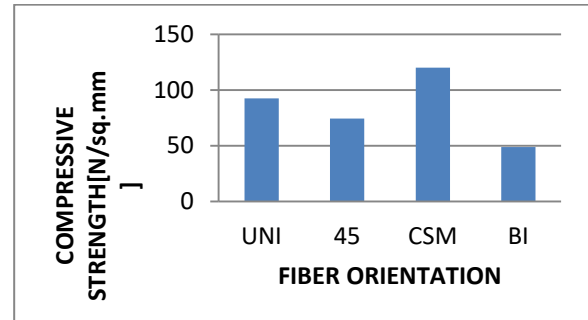


**Fig.7 Compressive Strength Vs L/D**

Among the **unidirectional orientation glass fiber** (TYPE-1) the specimen with an aspect ratio of 3.71 is having the highest compressive strength and the specimen with an aspect ratio of 7.41 is having the lowest compressive strength. The specimen with an aspect ratio of 5.56 has lesser compressive strength than that of 3.71 but the same specimen has greater compressive strength than the specimen of aspect ratio 1.85.

**Comparison among various fiber orientations with aspect ratio-1.85 (Fig.8)**

Among the glass fiber specimen of **aspect ratio 1.85** chopped strand mat layered glass fiber (TYPE-2) specimen is having the highest compressive strength (compressive) and the specimen with bidirectional orientation (TYPE-3) is having the lowest compressive strength.



**Fig.8 Compressive Strength Vs Fibre Orientation**

The specimen with unidirectional orientation (TYPE-1) is having lesser compressive strength than the CSM (TYPE-2) but the same specimen has greater compressive strength than the 45-degree cross-ply orientation glass fiber (TYPE-4) specimen.

## XI. CONCLUSION

From the torsion test performed and the comparative analysis conducted among the various fiber orientations incorporated glass fiber cylindrical specimen, it could be concluded that the TYPE-4 specimen is having the highest torsional strength in comparison with other types. While the TYPE-3 specimen is having the least torsional strength. Thus the TYPE-4 specimen could be highly suggested for the low power transmitting torsional applications compared with other glass fiber specimens.

From the tear test performed using a tensile tester and the comparative analysis performed between various cylindrical samples incorporating glass fiber orientation, it was concluded that the surface tear strength of the TYPE4 sample exceeds 2500 N. However, the actual dismantling point was not found. On the other hand, the TYPE3 sample has the lowest tear strength compared to other types. From compression, testing, and comparative analysis performed on different fiber orientations of cylindrical fiberglass samples, it could be

concluded that TYPE1 and TYPE2 samples have relatively higher compressive strength than TYPE3 and TYPE4 samples. From the compression tests performed and comparative analysis performed at different aspect ratios, the 7.41 aspect ratio cylindrical fiberglass sample has the lowest compressive strength compared to other samples with 5.56, 3.71 and 1.85 aspect ratios. Thus the glass fiber hollow cylindrical fabricated with unidirectional orientation and chopped strand mat layers having lesser aspect ratios could be suggested for high axial compression loading applications.

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